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April 27, 1965

Dr. T. L. K. Smull, Director
Grants and Research Contracts Division
Office of Space Science and Applications
Code SC
National Aeronautics and Space Administration
Washington, D. C. 20546

Dear Dr. Smull:

The letter and the attached individual project progress reports constitute the semi-annual status report on the research work supported by NASA under Research Grant NSG 713 to the University of Arkansas entitled "Investigation of Laser Properties Relevant to the Measurement of Different Physical Parameters" for the period September 1, 1964 through February 28, 1965.

In general the above period of time was involved in the acquisition of several laser systems and the initiation of theoretical and experimental evaluation of several original ideas. Some of the ideas still appear to be feasible while others have been rejected after their investigation.

Listed below are several ideas that have been advanced for future evaluation relative to the feasibility of using the various types of lasers as an integral part of a system. To qualify for investigation or experimentation, the system must utilize the laser in a unique manner, improve accuracy or sensitivity over existing devices, or allow simplification of the device or its auxiliary equipment. It should be noted that no theoretical or experimental evaluation has been performed to date on the ideas presented below.

FUTURE WORK

1. A pressure gauge that would have a range from atmospheric pressure to 10^{-7} torr.

The operation of several pressure gauges utilizing viscous or molecular drag is well known. These gauges are very useful for permanent laboratory vacuum systems, but they have not gained a high degree of popularity because of their fragile nature, susceptibility to mechanical vibration, and non-continuous readout. If a device were excited by a known force, either continuous or impulse, and its physical movement was a function of the viscosity or molecular drag of the gas within the system, a cw gas laser could be used to monitor the action and its variations with changes in pressure. The Doppler frequency work, that was previously performed on the momentum detector, may be applicable in this study.

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2. A surface roughness evaluation device that utilizes interference or Doppler frequency shift.

If a uniform reflecting surface is moved through a laser beam, the irregularities of the surface, should give rise to a variation in the nature of the reflected and scattered radiation. If the reflected radiation is then heterodyned with the incident radiation, the resulting signal possibly would give an indication of the distribution of the sizes and types of irregularity by means of a spectrum analyzer measuring the power spectrum of the heterodyned signal. A detailed theoretical analysis of the signal detection problem would have to be made to determine feasibility.

3. Microphone frequency response calibration can easily be accomplished using a laser. Capacitive microphones that have high frequency capabilities (100 KC) can be excited and the Doppler frequency pattern produced by the heterodyning of the reflected laser light from the microphone will give a clear indication of the frequency of operation. As the microphone exciting frequency is varied an accurate frequency-amplitude response curve for the microphone may be established.

4. A method of measuring the angular velocity and/or acceleration of a rotating device such as an ultra-centrifuge.

A device of this type might be used where surface requirements of the rotating equipment will not allow markings of any type on the surface. The velocity would be measured by taking the light scattered in the direction of rotation and the light scattered in the opposite direction, mixing the two scattered radiations together and obtaining a double Doppler frequency shift.

5. A flow meter somewhat different from the one currently being evaluated in that it would be useful for both liquids or gases and could be used for "on line" quantitative work. It would consist of a laser beam that has been projected through, reflected, or scattered by the fluid flow and the desired information obtained by the detection of the frequency of the radiation that has interacted with the fluid.

Sincerely yours,



M. K. Testerman
Principle Investigator

MKT/ac

Level Detection by Simple Interference Effects
G. H. Cline

Introduction

Investigations have been carried out to demonstrate the feasibility of using various simple interference effects to create a very sensitive and accurate leveling device. A liquid must be used as one of the optical surfaces in an interferometric device of this type because its surface plane is perpendicular to the pull of gravity and is an absolute quantity at given coordinates on the earth's surface.

Work Performed

Newtons rings, created by conventional means, were mathematically investigated and observed with an optical comparator. Angular variations of under 10 seconds of arc are readily detectable upon adequate magnification. If the contacting surfaces creating the Newton's rings are separated, the rings collapse to the center. If a lens is suspended over a liquid surface and the liquid is contained in a cone, tilting the cone will cause the surfaces to separate. In other words, as the cone is righted from an off-level angle the rings would expand and stop, as the level is approached and realized. Mathematical investigations of the cone yielded $y = y_0 \left[1 - \frac{1.175 \times 10^{-11}}{\cos^2 \alpha} n^2 \right]$ where y = height of liquid; y_0 = initial height of liquid; α = half angle of cone; n = number of seconds of tilt. From the above calculations it can be seen that for very small values of n , the cone which contains the liquid becomes extremely large for a detectable change in the rings.

Present work is being performed using an optical flat supported a small distance above a liquid surface. When properly illuminated^{1,2} Fizeau type fringes will be localized in the space between the surfaces. The direction of the fringes are indicative of the direction of off-level angle, the number of fringes are indicative of the magnitude. A 3.1 cm diameter flat tilted 1 sec. will yield one fringe (bright to dark) pattern across the flat. The sensitivity is determined by the diameter and flatness of the flat, and the collimation, wave length, and monochromaticity of the light. A possible read out method involves a known initial tilt of the flat to form a small number of fringes. These fringes could be detected by properly oriented sensing devices. With the necessary servo-drive mechanism the flat could be positioned, with respect to the device being leveled, to maintain the relative fringe positions with respect to the sensing devices. If magnetostriction were used to position the flat, the current flowing in the properly oriented magnetostrictive devices would indicate the direction and amount of off-level angle.

Another method that could be used to detect the number and direction of the fringes is to physically move a photodetector about the periphery of the flat observing the light to dark bands. With the necessary servo-drive mechanism, the flat would be positioned until no fringes were present. The current through a magnetostrictive device would again indicate the off-level angle characteristics. The detectable off-level angles should be of the order of 0.1 sec. when using this device. In conclusion, a quite simple, sensitive, accurate, and automatic level indicator is expected to be effected.

¹ Oppenheim and Jaffe, "Interference in an Optical Wedge", American J. Physics, 24, 610 (1956)

² Born, Principles of Optics, The Macmillan Co., N. Y. (1959)

A Cell for Measuring the Index of Refraction of Liquids
G. S. Ballard

Introduction

The purpose of this project is to investigate and develop a device capable of measuring small changes in the index of refraction of liquids. The aim is not to extend present measurements to more significant figures, but rather to build a simple device for making fast, accurate, "on-line" observations. Such a device could be used as a tool in analyzing the composition of binary mixtures, in preparing a mixture to a given composition, or to monitor a time varying process.

Work Performed

The device under investigation consists of a rectangular cell with reflecting surfaces on two opposite sides and a movable mirror on one end (cf. figure 1).

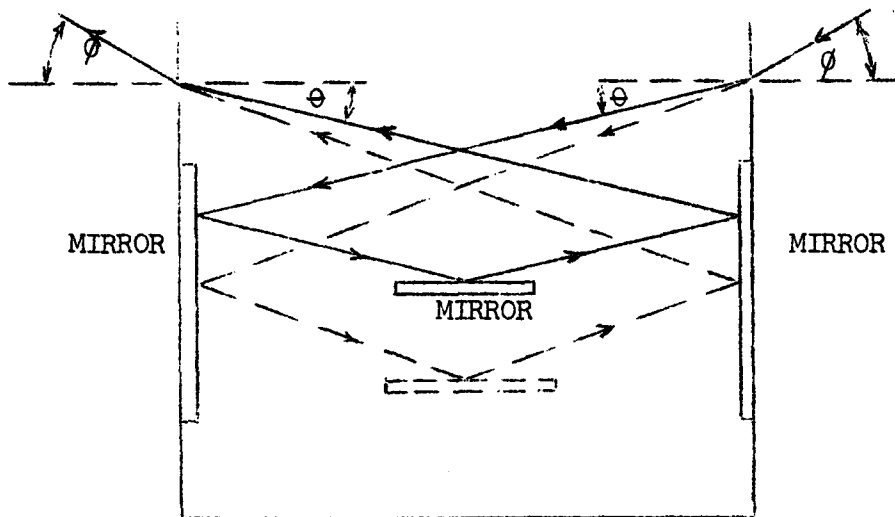


Figure 1

Light entering the cell at some angle of incidence ϕ is refracted to a new angle θ , determined by the index of refraction of the liquid in the cell. This beam of light is reflected in turn from the first side surface, the moveable mirror, and the second side surface. As it emerges from the cell, it will undergo refraction back to the original angle ϕ .

If a new liquid with a different index of refraction is placed in the cell, the angle θ will be different, and the light through the cell will follow the dotted path. The end mirror must be adjusted for the light to emerge at the same

point. Thus, the location of the mirror is related to the refractive index of the liquid in the cell.

A cell 2 inches x 2 inches has been constructed and tested. A He-Ne laser was used as the light source, making use of its characteristics of monochromaticity, collimation, intensity, and small beam diameter. The movable mirror was adjusted by means of a micrometer. The null signal from two matched silicon voltaic cells was used to detect the location of the exit beam. Measurements were made on several liquids whose refractive indices ranged from 1.33 to 1.58, and the results agreed quite well with the values obtained from the calculations.

A second cell has been designed which will span a range of refractive indices from 1.333 to 1.360 for a one inch movement of the mirror. Figure 2 presents a theoretical performance curve for this cell. The cell itself is 1 inch wide and approximately 10 inches long. If the signal from the detectors cause the movable mirror to be set within an accuracy of 0.004 inches, this will permit accurate reading of the index of refraction to the nearest 4th decimal place. At present, these readings are being made within 0.005 inches with water in the cell, and refinements in detection and in rigidity of the components should improve its performance.

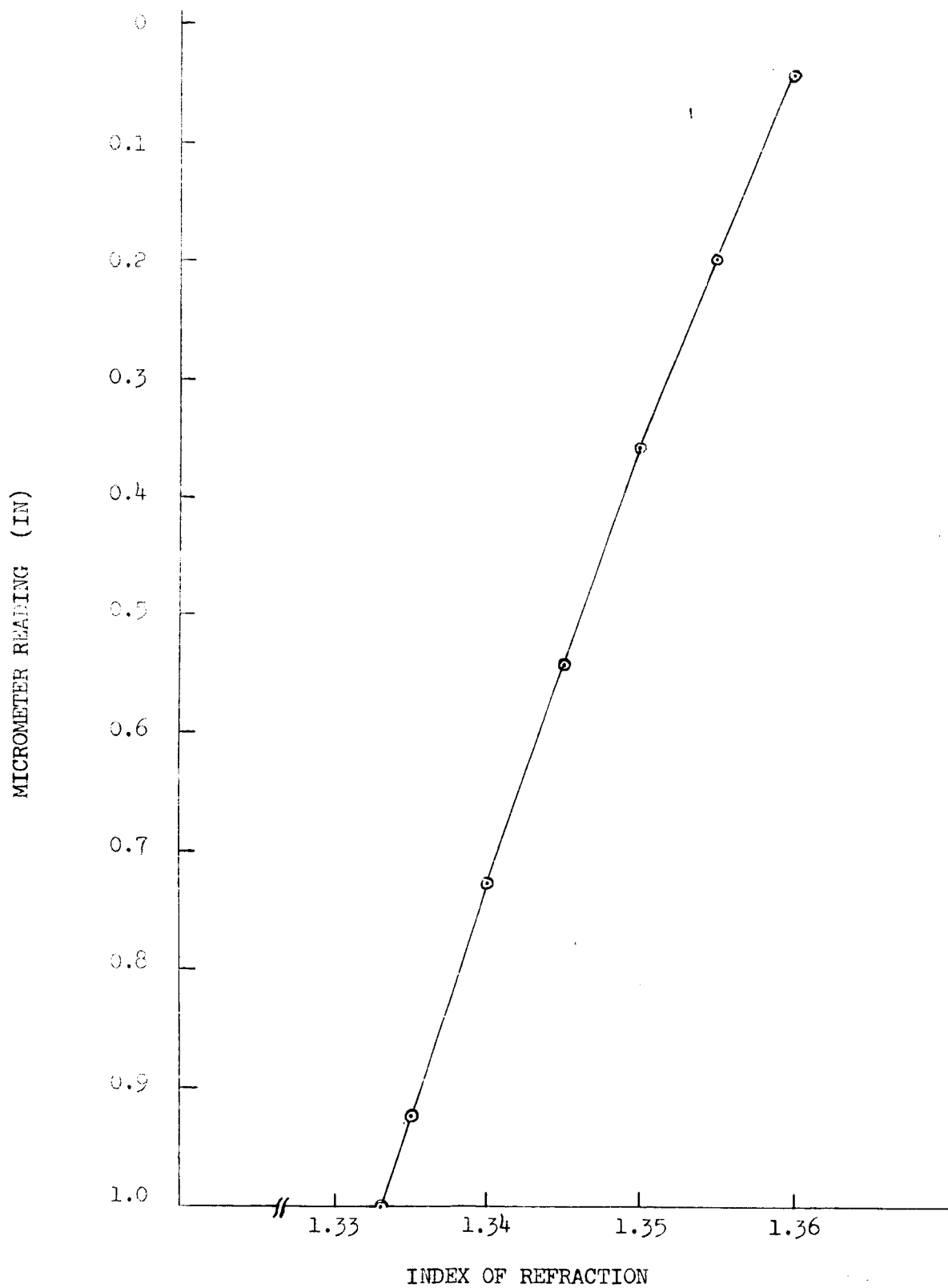
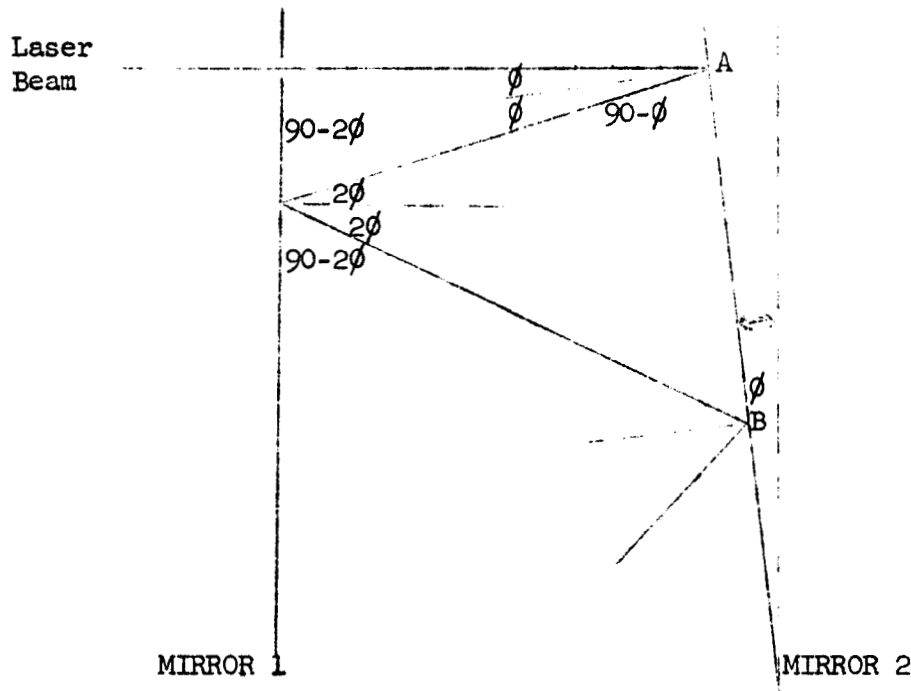


Figure 2

Alignment by Multiple Reflections
J. McElroy

Introduction

It has been proposed that a cw laser be used as an alignment device using multiple reflections between two plane mirrors. Consider the figure below:



The laser beam would be directed through an aperture in mirror 1, which would be perpendicular to the beam. The beam would then be incident upon mirror 2, attached to the object which is to be aligned. If mirror 2 is not parallel with mirror 1 by an angle ϕ , the angle of incidence of the beam on this mirror would be ϕ .

As the beam is reflected between the mirrors, a series of images due to the multiple reflections would be formed, and as mirror 2 is brought into parallel with mirror 1, the images would converge into one image.

This converging action could be determined by a system of photo detectors located at either mirror. If the detectors were capable of sensing the direction of movement of the images, the alignment could be made automatically.

Work Performed

Some investigation has been made into the probable sensitivity of this device. It is apparent that the size of the beam will be one of the major factors affecting sensitivity, since detection will depend upon determining the distance between the primary reflection and anyone of the succeeding reflections. For example, it has been found that for a mirror separation of 1 meter a distance between points A and B of 2 mm corresponds to an angle of 1.6 minutes. As the distance is increased or the beam size is decreased, smaller angles can be measured.

The divergence of the laser beam will also limit the accuracy of this device.

Conclusion

It has been concluded that a device of this type will not be extremely accurate but its merits lie in its simplicity and the large variety of applications that might be possible.

Measurement of the Index of Refraction of Gases
C. W. Young

Introduction

Some of the earliest and most accurate methods of measuring the index of refraction of gases utilized interferometric techniques. Since the continuous gas laser lends itself readily to the various types of interferometry, it was proposed that it might be possible to increase the accuracy of some of the present measurements by fabricating a very accurate, precise interferometer with a laser as the light source.

Work Performed

During the investigation it was learned that many times it is not the interferometer that limits the accuracy of measurement, but the control of temperature and pressure to very precise values. It has been calculated that it would be necessary to control the temperature to within 0.001 degrees centigrade to improve the accuracy of present values. A study of many different types of interferometers and experimental work with some of the different configurations was performed in order to determine if there might be a particular type of interferometer that would lend itself to the measurement of index of refraction of gases where the environment of the gas sample cell could be controlled very closely. A satisfactory solution has not been found and since the original problem has become an investigation of environmental control methods, the project has been terminated.

A large amount of useful information relating to interferometers and interferometry technique was gained while performing this work.

Pressure Determination by Rayleigh Scattering
P. C. McLeod

The system for Rayleigh scattering measurements at low pressures is 90% complete. This system is constructed from 304 stainless steel centrifugal castings and heliarc welded to insure proper sealing. Two ports with brewster windows are provided for incident beam passage and five equally spaced ports are provided for observation of the scattered light at angles from normal to $\pm 60^\circ$. The windows on the incident beam ports will be rotatable so measurements may be made normal to as well as in the same polarization plane as the laser beam. Pressure will be monitored by ionization techniques in the range of interest or from 2 torr to 10^{-10} torr. The success or failure of this part of the investigation will dictate whether or not calibration measurements at a pressure less than 10^{-10} torr are necessary and if so what the requirements may be. The construction of this system is such that it may be applied to other measurements and techniques, some of which are outlined in the section of this report entitled Future Work. It is anticipated that the complete system will be ready for use in 4 weeks.

Momentum Detector
P. C. McLeod

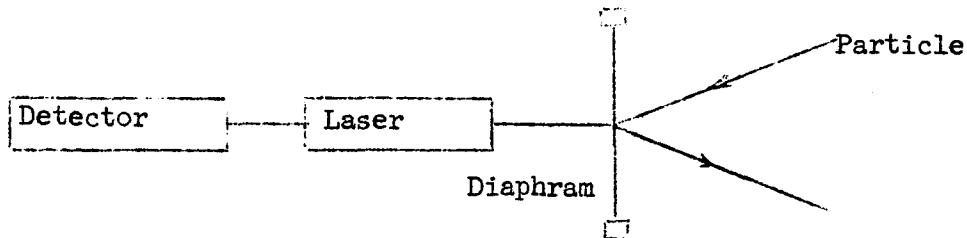
Introduction

When a laser beam is employed in a typical interferometer, very small movements of the reflecting mirrors can be observed as interference fringes. If the velocity of the reflecting surface is high, the rate at which the fringes occur is very rapid. For example, if the reflecting surface is moving toward the laser beam at a rate of one centimeter per second the fringe rate would be on the order of 30,000 fringes per second. (This technique, of course, is the Doppler method of measuring velocities.) If the movement of the reflector was due to a collision between the reflector and a small particle, the velocity of the combined pair could be monitored as a Doppler frequency shift, resulting in an effective measure of the momentum of the particle that caused the reflecting surface to be disturbed, provided the characteristics of the reflector is known.

Work Performed

At the time testing began, one limitation was known, that being the frequency response of the photodetector and its supporting electronics. Since it is desirable to keep the electronics in the RF range, the reflector velocity should never exceed 100 meters/second which is equivalent to approximately 300 megacycles/second frequency shift. During testing, however, a second and very severe limitation appeared. The problem involved the inability to maintain optical alignment during the time that the reflecting surface, in this case a diaphragm, was being deflected. The seriousness of this may be seen by the fact that the test velocities were on the order of 100 centimeters/second or roughly 1% of the allowable maximum velocity. The particles used were spherical with a mass range of 2 to 122 milligrams resulting in a range of momenta from 9.17 to 14.00 dyne-centimeters. The only time during the tests that Doppler effects could be observed was when the particle hit the diaphragm at the center

of the laser beam so that the beam alignment was not lost.



Under these conditions very sensitive measurements of momentum can be accomplished but the device depends on an extremely small sampling area. Diffused beam techniques among other things were employed to remedy this problem; however, under all conditions, intensity changes due to loss of alignment were serious.

Conclusions

Methods employed in existing momentum detectors were reviewed to see if laser techniques could be incorporated. It is doubtful that the use of a laser would increase the sensitivity or range of measurements enough to warrant the additional complication necessary to incorporate a laser into existing devices. Therefore it was decided that this investigation should be terminated. Much experience was gained in observing moving bodies by interferometric methods and other uses of this technique will be considered since it allows the measurement of the velocity, displacement, and period of a vibrating body at considerable distances and requires only the reflection of a laser beam to achieve these measurements.

A Fast and Accurate Means of Measuring and Adjusting Gas Flow Rate

G. S. Ballard

Introduction

At the present time, gas flowrate can be measured by noting the time required for the gas to force a bubble up a calibrated tube. This is presently a "hit or miss" affair, requiring visual observation of the bubble's velocity, manual adjustment of flowrate, another observation, further adjustment, and so on until the desired flow is reached. This can be quite a time consuming process. If the velocity of a bubble could be adjusted quickly, accurately, and continuously, an appreciable amount of time could be saved.

Work Performed

An attempt is being made to measure this velocity by means of the Doppler frequency shift of light reflected from the surface of the moving bubble. A rising bubble with a velocity of one cm/second gives a Doppler frequency shift of approximately 31 KC.

A He-Ne laser has been used as a light source, providing a monochromatic, well-collimated, intense beam. Ample light has been reflected from the bubble to be detected by a photomultiplier. Thus far, the instability of the bubble surface has made it extremely difficult to heterodyne this reflection with a reference beam. Also, the curved surface of the bubble makes alignment quite critical.

Conclusion

A device is now being constructed which will allow accurate alignment and more stable mounting of the various components. Upon its completion several methods will be investigated in an effort to obtain a more stable mixing of the reflected and reference beam. The results of these investigations will determine the practicality of this method of measuring the bubble velocity.

Long Path Cells
J. B. Story

Introduction

One can use the small angle of divergence of a laser beam to advantage in the construction of very long path length sample-containing cells for the measurement of weak optical effects in a sample material. The laser beam will retain enough intensity for accurate measurement at much greater distances than would a divergent beam. The long path lengths may be attained by multiple reflections of the beam.

Work Performed

Halbach¹ has used such a system for the measurement of the Faraday rotation produced by a plasma. The Faraday rotation (of the plane of polarization) is produced by the passage of light through a magnetic field. Additional work in this area is not anticipated at present.

The initial goal of the long path length cell work will be the development of a polarimeter for measuring small rotations produced by optically active materials. Ordinary polarimeter cell lengths are limited by beam divergence and the resultant decrease in brightness.

A later modification of the cell might make it suitable for measuring the Kerr effect for only slightly active substances. The Kerr effect relates to the rotation of the plane of polarization of light by the passage of the light through an electrostatic field.

An additional application of the long path cell might be in monitoring the contamination of an atmosphere. The atmosphere monitored could be that of a spacecraft cabin, or it could be the natural atmosphere in a study of the "smog"

¹ Paper presented at 6th Annual Meeting, Div. of Plasma Physics, American Physical Society, New York, November 4-7, 1964.

problem. In the case of the spacecraft atmosphere, one might use a laser emitting at, say, the carbon-hydrogen stretch frequency. Absorption would indicate the presence of lubricant fumes, polymer plasticizer vapors, etc.

In the case of "smog" studies one would probably look at the light scattered by the particles. In this application the action of the long path cell would be somewhat different than in the previous cases. The multiple passes of the light through the atmosphere effectively increase the intensity of the scattered light from the laser beam.

Axicon Laser Alignment System
R. L. Bond

Introduction

It has been suggested that a long-range alignment device could be devised utilizing a laser as a light source and an axicon lens¹ to provide a well-collimated line of light. It was hoped that the gradual movement of a large mass could be monitored over a long period of time. The projection distance desired was at least 1000 yards. A system to accomplish this was shown to be impracticable due to the size of the axicon, power requirements for the continuous laser, and the stability of detection over periods of several weeks. Emphasis was shifted in an effort to devise a "laboratory size" system.

Work Performed

An axicon lens was designed that would give a maximum projection distance of 10 feet using a beam of parallel light 3 inches in diameter. It was calculated that a lens 3 inches in diameter, made of material with refractive index of 1.49 would require a cone angle of $177^{\circ} 04'$. This lens was made and its calculated value of beam length agreed well with the experimental value. The quality of the lens was not good. A great deal of light was scattered due to surface imperfections and poor quality optical material.

Conclusion

The maximum projection distance of the axicon beam is directly related to the cone angle of the axicon and the wave front (plane or spherical) entering the axicon. For a projection distance of only 10 feet a large cone angle is required. Increasing the diameter of the lens and impinging beam would increase

¹ J. H. McLeod, "The Axicon: A New Type of Optical Element", J. Opt. Soc. of Am. 44, 592 (1954)

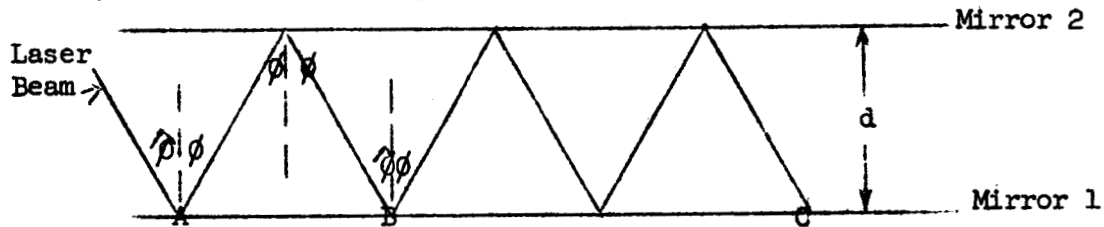
the projection distance but apparently, a well designed gas laser is superior to the axicon-laser system for alignment purposes over short distances. Thus it is seen that an alignment device of the axicon type would be of little value for the applications considered in this work.

Variable Optical Delay Line

J. McElroy

Introduction

It was proposed that a variable optical delay line be built utilizing multiple reflections between a pair of plane, front surface mirrors situated in a parallel, face to face configuration as shown below:



A ray of light incident on mirror 1 at an angle ϕ will be reflected at the same angle. Since the mirrors are parallel, the ray will be incident upon mirror 2 at the same angle.

The distance traveled by the ray during one round trip (two reflections) is $2d/\cos\phi$. During this time the ray will be displaced horizontally from A to B, the distance being $2d \tan \phi$. The number of round trips that the beam makes between A and C is given by $\frac{L}{2d \tan \phi}$, where L is the distance from A to C. The total distance traveled by the ray is the number of round trips times the distance traveled per round trip, or $S = \frac{L}{2d \tan \phi} \frac{2d}{\cos \phi} = \frac{L}{\sin \phi}$. The time required to travel this distance is $t = \frac{L}{C \sin \phi}$ where C is the velocity of light.

Work Performed

A pair of adjustable mirror mounts was fabricated and attempts were made to create a predictable delay. It was found that, for all the reflections to remain in a plane perpendicular to the reflecting surfaces, the mirrors had to be of high quality and adjusted very critically. The next step was to investigate the possibility of using spherical mirrors.

It was found, however, that Kurnitz¹ had used a similar method involving spherical mirrors with good results. With this information the project became a reduction to practice and the effort was terminated.

¹ Kurnitz, Abella, and Hartmann, Phys. Rev. Letters 13; 567, (1964)